THE DISCOVERY POTENTIAL OF SUPERSYMMETRY AT CMS WITHIN THE mSUGRA MODEL USING SAME-SIGN DI-MUONS

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A detailed study of the same-sign muon signature within the mSUGRA model is described. Selection criteria based on the missing transverse energy in the events and the jet and muon transverse momenta are applied. The results indicate that an excess of SUSY events over the Standard Model background processes can be statistically significant for an integrated luminosity of less than $10\mathrm{fb}^{-1}$ for many benchmark points with $m_{1/2}$ up to 650 GeV/c^2.

1 Introduction

The mSUGRA model is a popular simplification of the Minimal Supersymmetric Standard Model (MSSM) [1], with only five free parameters: $m_0, m_{1/2}, \tan\beta, A_0, \mathrm{sign}(\mu)$. In this study the following values of the parameters were used: $\mathrm{sign}(\mu) > 0$, $A_0 = 0$, $\tan\beta = 10, 20, 35$ and 20 $(m_{1/2}, m_0)$-points. All points were chosen so as to satisfy recent theoretical and experimental constraints [2].

The same-sign di-muon signature was chosen to evaluate the chances of discovering SUSY, since it is very clean, has high trigger efficiency and relatively small background. A recent published theoretical study of the signature at the Tevatron can be found in Ref. [3].

The aim of the present work was to investigate the region in the mSUGRA parameter space which is accessible to CMS at the LHC start-up.

2 Event Generation, Simulation and Reconstruction

Coupling constants and cross sections in the Leading Order (LO) approximation for SUSY processes were calculated with ISASUGRA 7.69 [5]. Next to Leading Order (NLO) corrections were calculated with PROSPINO [6]. Cross sections for SM processes were calculated using PYTHIA 6.220 [7] and CompHEP 4.2p1 [8]. For several SM processes ($\mathrm{t\bar{t}}, \mathrm{ZZ}, \mathrm{Zb\bar{b}}$), the NLO corrections are known and were used [9]. Preselection cuts were applied at generator level for signal and background requiring at least two same-sign muons with $P_T > 10$ GeV and $|\eta| < 2.5$.

Full simulation of the CMS detector was performed using GEANT-based CMSIM [10]. Data digitization and reconstruction were performed with the ORCA [10] reconstruction package. Pile-up was not taken into account in this study. It was verified that all events satisfying the selection criteria passed both L1 and HLT muon triggers.

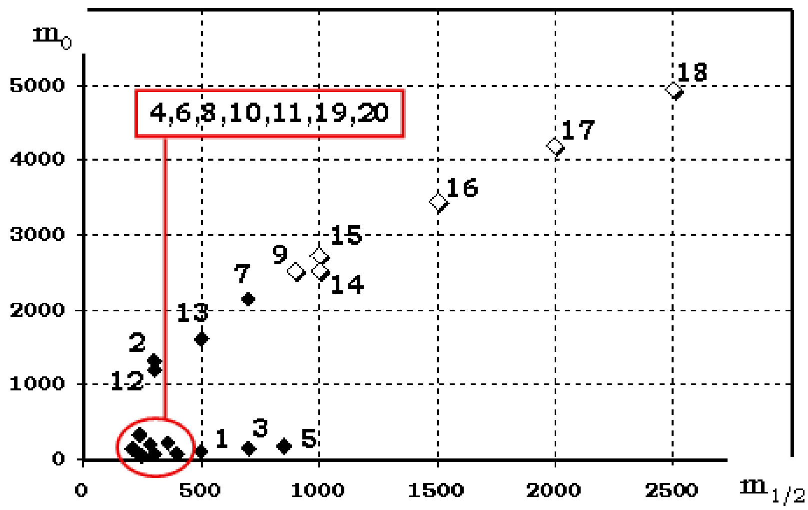

Figure 1: The mSUGRA benchmark points investigated in this analysis.

3 Signal processes

The 20 points chosen for this analysis are shown in Fig. 1. Points 2, 11, 16, 19 are mSUGRA benchmark points taken from Ref.[4] (two of them, points 2 and 16, were modified for a top-quark mass of 175 GeV as used for all other points).

For each mSUGRA point, the LO cross section was calculated and hence the number of events expected for an integrated luminosity of 10 fb^{-1}. NLO corrections were applied to the latter for all mSUGRA points. The six points shown on the plot by empty markers (# 9, 14-18) are found to have a cross section too small for a target integrated luminosity of 10fb^{-1} and are not considered further in the study.

4 Background processes

The cross sections and the number of generated and selected events for several sources of background are listed in Table 1. In the tb, tqb, $\bar{\mathrm{t}}$b, $\bar{\mathrm{t}}$qb processes, the top quark was forced to decay to Wb and the W was forced to decay into a muon and neutrino. In the Zb$\bar{\mathrm{b}}$ process, the Z/γ^* was forced to decay to $\mu^+\mu^-$, and these muons were required to have an invariant mass larger than 5 GeV/c^2.

The contribution of several other potential background processes were investigated: WWW, ZWW, ZZW, ZZZ, WWWW, ZWWW, ZZWW, ZZZW, ZZZZ, $\mathrm{t\bar{t}W}, \mathrm{t\bar{t}Z}, \mathrm{t\bar{t}WW}, \mathrm{t\bar{t}ZW}, \mathrm{t\bar{t}ZZ}$. No detailed simulation was performed for these processes. An estimation was obtained from the process cross section (calculated with CompHEP) and the branching fraction into muons. All but the $\mathrm{t\bar{t}W}, \mathrm{t\bar{t}Z}$ processes were found to be negligible and are neglected in this analysis. The $\mathrm{t\bar{t}W}$ and $\mathrm{t\bar{t}Z}$ backgrounds are also neglected here, but require further investigation. QCD multi-jet production is a further possibly significant background which is yet to be investigated.

5 Event Selection and cut optimization

The distributions of kinematic variables such as missing E_T, jet E_T and muon P_T are in general very different for SUSY and SM processes. Fig. 2 shows an example of these differences. Suitable cuts on such variables can therefore be used to suppress the SM background.

Table 1: Cross sections and numbers of events for SM processes for an integrated luminosity of $10fb^{-1}$. $N_{\rm generated}$ is the unweighted number of generated events, $N_{\rm selected}$ is the unweighted number of preselected events, N_1 is the number of events for an integrated luminosity of 10 fb^{-1}, N_2 is the number of events after preselection cuts (at least two same-sign muons with $P_T > 10$GeV/c.)

Process	σ, *pb*	$N_{\rm generated}$	$N_{\rm selected}$	N1	N2
tb	0.212	18,999	1,000	2,120	112
tqb	5.17	28,730	1,000	51,700	1,798
$\bar{\rm t}$b	0.129	13,588	745	1,290	71
$\bar{\rm t}$qb	3.03	28,359	1,000	30,300	1,067
ZZ	18(NLO)	433,489	1,000	180,000	256
ZW	26.2	368,477	1,000	262,000	727
WW	26.2	894,923	41	702,000	39.7
t$\bar{\rm t}$	886(NLO)	931,380	15,000	8,860,000	142,691
Zb$\bar{\rm b}$	232(NLO)	359,352	2,000	2,320,000	12,924
All					160,000

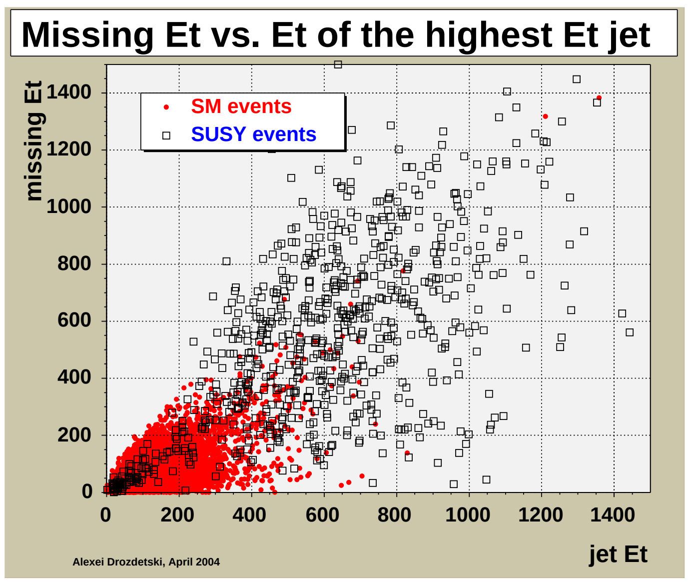

Figure 2: Missing transverse energy vs. jet E_T for SUSY (open squares) and SM events (points) after full simulation and reconstruction.

Five discriminating variables were selected: the total missing transverse energy, the transverse energy of the highest and third highest E_T jets, and the transverse momenta of the two muons. For each variable a set of possible selection cuts was defined. For each possible combination of these cuts for the five variables, the significance, the signal to background ratio and the number of expected events for $10fb^{-1}$ were calculated. The significance was calculated using the following expression [11]: $S_{12} = 2(\sqrt{N_S + N_B} - \sqrt{N_B})$, where N_S and N_B are the total number of signal and background events, respectively, at the mSUGRA point in question. An iterative optimization procedure was used to identify sets of cuts for which these three quantities are close to maximum for all mSUGRA points. The two sets of cuts shown in Table 2 were together found to satisfy this requirement.

6 Results

The expected number of signal and background events, the significance, and the signal to background ratio for each mSUGRA point studied are shown in Table 3.

Table 2: Chosen cut sets. E_{T,jet_1} is the E_T of the highest E_T jet, E_{T,jet_3} is the E_T of the third highest E_T jet, P_{T,μ_1} and P_{T,μ_2} are the two highest P_T values of the same-sign muons.

set	miss. E_T, GeV	E_{T,jet_1}, GeV	E_{T,jet_3}, GeV	P_{T,μ_1}, GeV	P_{T,μ_2}, GeV
1	> 200	> 0	> 170	> 20	> 10
2	> 100	> 300	> 100	> 10	> 10

Table 3: Expected number of events, significance and signal to background ratio after all cuts, for the 20 SUSY benchmark points considered. The "SM" row gives the expected number of the SM background events after all cuts for all considered processes. The indices set1 and set2 refer to cut sets # 1 and 2 respectively.

	N_{set1}	$S_{12,\mathrm{set1}}$	S/B_{set1}	N_{set2}	$S_{12,\mathrm{set2}}$	S/B_{set2}
SM	69.5±6.0			432±8.8		
1	95.9±6.7	9.05	1.38	184±9.3	8.06	0.43
2	282±20	20.8	4.06	560±29	21.4	1.3
3	17.7±1.1	2	0.25	30.4±1.4	1.44	0.07
4	365±73	25	5.26	1590±152	48.4	3.7
5	6.54±0.37	0.77	0.094	9.6±0.45	0.46	0.002
6	277±35	20.6	4.0	1030±67	35	2.4
7	6.7±0.35	0.78	0.096	8.31±0.39	0.4	0.019
8	188±17	15.5	2.71	530±28	20.5	1.2
10	515±78	31.7	7.41	1950±151	56.1	4.5
11	137±11	12.1	1.98	322±18	13.4	0.75
12	409±30	27.1	5.89	781±42	28.1	1.8
13	58.8±3.3	6	0.85	86.9±4	4	0.2
19	377±59	26.5	5.43	1220±106	39.8	2.8
20	279±36	20.6	4.01	996±67	34	2.3

In addition to the six points already excluded due to low cross section (see Section 3), three further points are out of reach (significance less than five) for 10fb^{-1} of integrated luminosity for both cut sets: points 3, 5 and 7. For the benchmark mSUGRA points with significance greater than five the signal to background ratios are greater than 0.4.

Referring to Figure 1, with points 3, 5 and 7 additionally excluded, an approximate sensitive area for 10fb^{-1} can be defined on the $m_{1/2}$ parameter axis as $m_{1/2} < 650$. In order to put bounds also on m_0 it is necessary to investigate more mSUGRA benchmark points with $m_{1/2} < 650$ GeV and $m_0 > 1500$ GeV.

7 First estimate of systematic effects

The stability of the significance with respect to the uncertainty on the signal acceptance and the background normalization was verified. A correlated variation of the SM event number (+30%) and expected number of SUSY events (−30%) was applied. It was found that the significance of only one mSUGRA point (# 13) drops below the discovery level.

8 Summary

A detailed study of the same-sign muon signature arising from 20 different points in the mSUGRA model was performed. The region in the $(m_{1/2}, m_0)$-plane with $m_{1/2} < 650$ GeV$/c^2$ is accessible by the CMS at 5σ level at the LHC start-up (10fb^{-1}).

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